Particle Production and Hyper-nuclei experiments

Radhey Shyam, SINF, Kolkata
R.Raja, FNAL, USA
A.Chatterjee, BARC, Mumbai
Current Indian activities in this field:

- COSY – BARC: Pionic atoms, Eta production, Eta mesic nuclei
- India collaboration at WASA(COSY), PANDA(FAIR) [IIT Mumbai, BARC, VECC]
- Contributions to theory (SINP)
- MIPP (FNAL)
• Eta-Nucleus bound state study and the ENSTAR detector:

• \( \eta \)-nucleus Final State Interaction Studies (\( \rho^6\text{Li} \rightarrow \eta^7\text{Be} \))

• Investigation of Charge Symmetry Breaking effects and pi-eta mixing angle from a precision measurement of

\[
R = \frac{\sigma(pd \rightarrow ^3\text{H}\pi^+)}{\sigma(pd \rightarrow ^3\text{He}\pi^0)}
\]

• High precision eta- mass measurement
Formation of Bound States

\[ p + A \rightarrow (A-2)\eta + ^3\text{He} ; \ A = ^6\text{Li}, ^{12}\text{C}, ^{27}\text{Al} \]

Strong indication of \( \eta \)-bound state in missing mass spectrum

Phys Rev C 70 2009 012201(R)
Phys Rev C 82 2010 041001(R)
Target: Pellete (H, D.. )
Nuclear: Foil, thin wire

Barrel DIRC:
Photon Counter + Elec. + Simulation

SiPM based fast Scint. Det.

Endcap DIRC:
Read-out

Forward TOF

Forward RICH

Calorimeter:
EM + Hadron, muon chamber

Luminosity Monitor

Target spectrometer: θ > 5 deg.
Located inside a solenoid, l=2.5 m, Ø= 0.8 m, B~ 2T

Forward spectrometer: θ < 5 deg. (vertical) & < 10 deg. (horizontal)
1. Interaction between nucleons and mesons in coupled channels K-matrix approach
2. Covariant theory for hypernuclear production using pion, proton and photon probes
3. Study of $K^- + p \rightarrow K^+ + \Xi^-$ reaction using effective Lagrangian model

R. Shyam, O. Scholten and A.W. Thomas, Submitted (2011)
Main Injector Particle Production Experiment at Fermilab (MIPP)

- MIPP – I has taken data and is analyzing results.
  - Has 2 Indian graduate students, several Indian visitors (U.Panjab, U.Banares)
- MIPP- II (Upgraded version of MIPP)
  - Electronics upgrade of MIPP-I (will run 150 times faster)
  - Can take place within 1 year of approval (i.e. many years before Project-X beams are available)
- Essential for neutrino experiments such as LBNE, INO
- Can use its charged kaon beams and excellent particle ID capabilities for hypernucleus physics
- Excellent venue to train graduate students from India
  - They get experience in hardware, commissioning the experiment, software and physics analysis in a period of 3 years.
- Indian institutions can contribute in testing and manufacturing the fast electronics needed.
MIPP Upgrade collaboration list

83 collaborators world wide, 15 from India

V.Singh, Banaras Hindu University, Varanasi 221005, India

M.R.Anantharaman, V.C.Kuriakose, M.Sabir, R.B.Thayyullathil
Cochin University of Science and technology, Kochi 682022, India

B.C. Choudhary, University of Delhi, Delhi 110007, India

B.Bambah, R.Mohanta, E. Harikumar, University of Hyderabad, India

A.K.Giri, Indian Institute of Technology, Hyderabad, India

V.Bhatnagar, A.Kumar, S. Mahajan, S. Sahijpal, A. Singh
Panjab University, Chandigarh, 160014, India

Ambar Chatterjee, BARC
Brief Description of Experiment

• Situated in Meson Center 7
• Uses 120GeV Main Injector Primary protons to produce secondary beams of $\pi^\pm K^\pm p^\pm$ from 1 GeV/c to 85 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
• Using a TPC (Time Projection Chamber), MIPP measures momenta of ~all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, MultiCell Cherenkov and RICH technologies.
• Open Geometry- Lower systematics. TPC gives high statistics 3D track reconstruction.
• Upgraded detector will run 150 times faster and will produce 5million events per day.
• Addition of the GSI Plastic Ball detector will enhance MIPP nuclear physics and hypernucleus capabilities.
• MIPP-I data is being analyzed. Major publications soon.
• Nova/ Minerva medium energy target measurement.-15 million events in 3 days
• LBNE target design and particle production measurements
• Improve shower simulators (MARS, Geant4..). Plastic ball recoil detector will detect recoil neutrons from nuclei. Important for calorimeter compensation mechanisms.
• Measurement of production on nitrogen for cosmic ray + atmospheric neutrino experiments. Essential for INO.
• Hypernucleus physics using charged kaon beams and identified kaons and lambda particles in the final state.
• Missing Baryon Resonances measurements
• More detailed Studies of the strong interaction using excellent acceptance and particle identification
• Beams of tagged neutrons (where neutron energies are known event to event) have been demonstrated. Useful for nuclear physics
Installed in 2003. Excellent performance. Ran it successfully in MIPP from 5-85 GeV/c secondaries and 120 GeV/c primary protons. Excellent particle ID capabilities using 2 Beam Cerenkovs. 6 beam species ($\pi^\pm, K^\pm, p^\pm$) in the momentum range ~1-120 GeV/c
MIPP
Main Injector Particle Production Experiment (FNAL-E907)
RICH rings pattern recognized
Beam Cherenkovs – Helps identify beam particle

+40 GeV/c

-40 GeV/c
Comparing Beam Cherenkov to RICH for +40 GeV/c triggers – No additional cuts!

![Distribution of RICH Ring Radii in Beam](image)

![Distribution of RICH Ring Radii with Proton Trigger](image)

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![Distribution of RICH Ring Radii with Kaon Trigger](image)

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![Distribution of RICH Ring Radii with Pion Trigger](image)
The MIPP Upgrade Proposal in a nutshell

- MIPP upgrade consists of replacing the electronics of every sub-detector using more modern designs. For the TPC electronics, ALTRO/PASA chips have been acquired and prototype boards have been designed.
- The Plastic Ball detector will be added as a new system to detect recoil pions, protons, neutrons and photons (below ~100 MeV in energy).
- All sub-detector electronics are in prototype stage. Each card has been designed.
- Total estimated cost of fabricating the electronics if done in the U.S is ~$1 Million (Rs 4.5 Crore).
- Upgrade essentially consists of fabricating the electronics board in quantity and testing them.
- Upgrades to the beamline, rewinding the TPC and upgrades to the DAQ complete the list.
Meurer et al – Cosmic ray showers Discontinuity-Gheisha at low energies and QGSJET at higher energies - Simulation of air showers. This problem cannot be solved by measuring a nitrogen target at one or two energies.

Cosmic ray showering not understood. 2 models show a factor of 2 discrepancy. Nitrogen measurements by MIPP will fix this.
INO hopes to measure the sign of $\delta m^2_{32}$ by measuring the difference between neutrino and anti-neutrino induced events where the neutrinos are produced by cosmic ray showers in the atmosphere. In order to have maximal sensitivity for this measurement, it is essential to know the relative rates of positive and negative pions produced in atmospheric showers.

MIPP upgrade can measure the production of pions in nitrogen using proton and pion beams in the relevant energy range. The maximum of the cosmic ray showers happens to be at approx. the MIPP energy ranges.
Detect recoil protons, neutrons, photons and charged pions, kaons.
Tagged Neutron candidates observed in MIPP data

Tagged neutral candidate 2 – 58 GeV pp interaction

By measuring the final state proton and pion momentum, the neutron momentum can be tagged. Neutrons as low as a few 100 MeV can be produced in the tagged mode.

<table>
<thead>
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<th>Beam Momentum GeV/c</th>
<th>Proton Beam n/day</th>
<th>K+ beam K-Long/day</th>
<th>K- beam K-Long/day</th>
<th>Antiproton beam anti-n/day</th>
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MIPP upgrade will have kaon beams of both charges from 3 GeV/c up to 85 GeV/c.

The plastic ball recoil detector can detect recoiling neutrons, pions, photons and protons from nuclear breakup.

The TPC can measure the identity of the nuclear fragment by dE/dx for momenta below 1 GeV/c.

Charged particles in the final state can be identified by TPC, time of flight, multi-cell Cerenkov and RICH technologies for the full momentum range.

Strange neutral particles, K-Shorts, lambdas and anti-lambdas can be identified in the TPC.

Using this arsenal of technologies, it should be possible to search for hyper nuclei of single and double strangeness.
Five PhD's awarded

- Ratio of Pion Kaon Production in Proton Carbon Interactions (A. Lebedev, Harvard)
- Measurement of Pi-K Ratios from the NuMI Target (S. Seun, Harvard)
- Measurement of the Charged Kaon Mass with the MIPP RICH (N. Graf, Indiana) (published)
- Charged pion production cross section using 120 GeV/c proton beam on carbon target (G. Aydin, Iowa)
- Cross section measurements in the Main Injector Particle Production (FNAL-E907) experiment at 58 GeV/c (Y. Gunaydin, Iowa)

2 Indian students (Sonam Mahajan and Amandeep Singh from U. Panjab, Chandigarh) are at MIPP currently working on their theses.

In addition, Dr. Ashok Kumar( Chandigarh), Dr.Venktesh Singh(Fermilab International Fellow, Banares), Arun Soma(Banares), Sourav Tarafdar(Banares) have spent time at MIPP as visitors.

This can increase significantly with Indian participation in MIPP Upgrade.
Notice discrepancies between the 2 Monte Carlos and also the data and the Monte Carlos
Actual NuMI target in MIPP upstream of the TPC. This target was then installed in NuMI.

Radiograph of NuMI target in MIPP taken with a defocused 120 GeV/c proton beam
Event Displays

NuMI target data event

NuMI target Monte Carlo event with run dependent imperfections added
MIPP detector responses

Delhi Meeting June 17, 18 2011
Ambar Chatterjee, BARC
Comparison of Data with MC for negatives

![Graphs showing comparison of data with Monte Carlo for different particles.](image-url)
Comparison of Data with MC for positives

- Momentum positive Electron
- Momentum positive Pion
- Momentum positive Kaon
- Momentum positive Proton
TPC boards-New Prototypes vs old

Old Stick

New Stick

Single Altro/Pasa unit

Buffer Board
Drift Chamber/ PWC readout Upgrade

- Large PWC’s use old CERN RMH electronics- Needs replacement.
- MIPP proposes a unified scheme for reading out both sets of chambers using a system that modifies the MIPP RICH readout cards by changing the latch to a TDC.
- Preamp cards being replaced Preamp/Discriminator front end cards.
- The RICH cards will store an entire spill’s worth of events, which are readout in between spills.

8 Channel amplifier card
Chamber Card prototypes

32 channel amplifier card

96 channel TDC card
TOF & CKOV readouts

• 106 TOF + 12 T0 +96 Ckov channels
• Plan to use the back end provided by MIPP readout controller.
• Front end likely to be TriP-T chip (also used by MINERvA(ADC)) and a high resolution TDC chip (TDC-GPX from ACAM 30ps resolution). Will buffer an entire spill. Delay cables will be eliminated.
Plastic Ball Recoil Detector

• Plastic ball detector is available. GSI/KVI have joined MIPP. We will install a hemisphere in MIPP. Mounting details to be worked out. Need the ability to remove the detector to repair it and the TPC.

• Transportation to Fermilab.

• GSI/KVI will play a lead role in making this happen.

• Detector will help in all aspects of MIPP data including tagged neutral beams, missing baryon resonances and hadronic shower simulation data.
Plastic ball readout

Plastic ball front end board

Plastic ball front end board schematic

4 channels

Plastic ball trigger logic
EM Calorimeter wire amplifier board

EM cal front end board

Block diagram of EM cal front end 8 channel wire amplifier board

EM cal front end 8 channel wire amplifier board

HCAL has currently 8 PMT/ADC channels. We plan to adapt a plastic ball readout module for this.
• MIPP Upgrade experiment will permit high quality, high statistics data on hadronic production to be acquired in a timely fashion.

• Data thus acquired needed by a variety of clientele.

• India stands to gain in the following areas.
  – Training new students in hardware, software and analysis techniques.
  – acquiring data needed for the INO
  – Participating in search for hyper nuclei
  – Acquire skills needed in fabricating state of the art electronics.
Thank You
**What are Hypernuclei**

- Hypernuclei are systems where at least one nucleon is replaced by a hyperon ($\Lambda$ discovered 1953 – emulsion experiment).
- The hypernucleus is a laboratory to study hyperon-nucleon (YN) and hyperon-hyperon (YY) interactions.
- Multi strangeness hypernuclei $\Leftrightarrow$ Neutron stars (high core density).

Internal nuclear shells are not Pauli-blocked for hyperons.
A hypernucleus can be considered the outcome of a genetic engineering manipulation applied to the nuclear physics domain.

The introduction of 1 (or 2) hyperons in a nucleus may give rise to various changes of the nuclear structure:

- changes of the size and of the shape
- changes of the cluster structure
- manifestation of new symmetries
- change of collective motions

$S = -2$ systems study is not just a simple extension of what has been done for $S = -1$ system.
A detailed and consistent understanding of the quark aspect of the baryon-baryon force will not be possible unless information on YY systems is available.

Production of Hypernuclei at J-PARC by (K−, K+) reaction. Also possible in Project-X, MIPP experiment.

Existing information

S = -1 hypernuclei
Beginning evidence for S = -2 Ξ hypernuclei (BNL and J-PARC followup)

Needed

Clear observation of Ξ and Λ Λ hypernuclei
Ω hypernuclei (S = -3)
Neutron rich ΛA
Decay widths especially non-mesic channels ΛN → NN
Missing baryon Resonances

• Partial wave analyses of $\pi N$ scattering have yielded some of the most reliable information of masses, total widths and $\pi N$ branching fractions. In order to determine couplings to other channels, it is necessary to study in elastics such as

$$\pi^- p \rightarrow \eta n; \pi^- p \rightarrow \pi^+ \pi^- n; \pi^- p \rightarrow K^0 \Lambda$$

$$\gamma p \rightarrow \pi^0 p; \gamma p \rightarrow K^+ \Lambda; \gamma p \rightarrow \pi^+ \pi^- p$$

• All of the known baryon resonances can be described by quark-diquark states. Quark models predict a much richer spectrum. Where are the missing resonances? F.Wilczek, A. Selem

• “..this could form the quantitative foundation for an effective theory of hadrons based on flux tubes” – F.Wilczek
Nuclei of interest- 1\textsuperscript{st} pass list

- The A-List

- $H_2, D_2, Li, Be, B, C, N_2, O_2, Mg, Al, Si, P, S, Ar, K, Ca,,Fe, Ni, Cu, Zn, Nb, Ag, Sn, W, Pt, Au, Hg, Pb, Bi, U$

- On each nucleus, we can acquire 5 million events/day with one 4sec beam spill every 2 mins and a 42% downtime.

- We plan to run several different momenta (1-85 \text{geV/c}) and both charges. For neutrinos we will also have $p=120 \text{GeV}$ on thick and thin targets.

- The libraries of events thus produced will be fed into shower generator programs which currently have 30 year old single arm spectrometer data with high systematics.